The TREND IN ENGINEERING

at the University of Washington

In this issue:

THE UNIQUE PROPERTIES OF FLEXURE PIVOTS

A PHOTOGRAPHIC METHOD FOR DETERMINING THE DEFLECTED SHAPES OF BUCKLED PLATES

A METHOD OF SEPARATING AND CONCENTRATING CINNABAR BY FLOTATION

EXPERIMENT IN SPACE-FLIGHT LIVING ECONOMY

NEW REACTOR AND BUILDING TO MATCH GRADUATE NUCLEAR PROGRAM

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NOT JUST TO SELL*

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Harvey Mudd College of Science and Engineering

The title of this paper comes from an incident told by Alfred P. Sloan about the days when as a young man he was trying to keep the Hyatt Roller Bearing Company in business. When he received a complaint from one of his best customers that bearings provided for Cadillac cars were not satisfactory, he went to Detroit to talk to the founder and president of the Cadillac company, Henry M. Leland. Leland showed Sloan some of his bearings which were not within the agreed tolerance of a thousandth of an inch and said, "Mr. Sloan, Cadillacs are made to run, not just to sell." He waved aside Sloan's excuses and went on, "You must grind your bearings. Even though you make thousands, the first and last should be precisely alike."

Mr. Sloan ranks this encounter as a landmark in his career. It gave him a new concept of mass production, and he came away with a resolve to be as fanatical about precision as Mr. Leland. Suppose then, we look at the man who expounded the philosophy and provided the inspiration. Henry Martyn Leland was a Vermonter with a long training as machinist and toolmaker. After twenty years at Brown and Sharpe's in Providence, R.I., he and two other Brown and Sharpe men went into the machine tool business on their own in Detroit in 1890 as Leland, Faulconer and Norton. When Norton returned to New England to work on his grinding machine, the firm became Leland and Faulconer, with a high reputation as makers of precision tools. Faulconer, for instance, was the inventor in 1899 of a machine for grinding the hardened bevel gears of chainless bicycles†—and it may be noted that ability to work with alloy steels was essential to the growth of the automobile industry.

When the demand for machine tools dropped in the depression of 1893, Leland and Faulconer expanded their operations to the manufacture of gasoline engines for motor boats, and this interest in turn drew the firm into motor vehicle production as a supplier of engines for Oldsmobiles when the Olds factory in Detroit burned down in 1901. Then Henry Leland was called on to rescue the backers of Henry Ford's second unsuccessful venture into the automobile business, with the result that what had been the Henry Ford Company was merged with Leland and Faulconer in 1904 as the Cadillac Motor Car Company.

By this time Henry M. Leland had passed the age of sixty, but he was still able to make a lasting contribution to the American automobile industry. He gave to the Cadillac car the reputation for superiority which it has managed to retain, his two most spectacular triumphs being a demonstration of interchangeability of parts which won the British Dewar Trophy in 1908 and the introduction of the electric starter in 1912. Then, to crown an astonishing career, when he was seventy-five he left Cadillac to make aircraft engines during the First World War and on the return of peace gave the automotive world another quality car in the Lincoln—although it was not, for him, the commercial success that his first venture had been.

Leland's achievements were based on the two principles he taught Sloan and other future leaders of the automotive industry. The first was a rigorous standard of accuracy, as applicable to production in quantity as to hand-tooling methods of manufacture. The second was his insistence that the customer should be sold a product which would do what its manufacturer claimed it would. The one test which mattered to Henry M. Leland was performance. It is perhaps just as well that he did not live to see the automobile industry undergo a phase in which glitter on the outside would be considered to have a stronger sales appeal than technical merit on the inside.

At any rate, Leland's position was the direct antithesis of the doctrine of *caveat emptor*. He was certainly neither the first nor the only business man to take this position, but as an admired and respected automotive pioneer he was strategically placed to impress his ideas on the automobile industry and thence on the mass production industries in general, since the makers of washing machines, refrigerators, televisions, and so forth, have in the main followed the patterns initiated by the automobile manufacturers. All of them are producing goods whose technical features cannot possibly be evaluated by the ordinary purchaser. Without the kind of confidence in the reliability of the manufacturer created by a business philosophy of "made to run, not just to sell," it is doubtful if the free marketplace which is the foundation of our economic system could survive.

One example, of course, does not establish a type, but there are others. We might consider two of Leland's contemporaries, Worcester Warner and Ambrose Swasey. Like Leland, they were trained as machinists but crossed the vague boundary which in those days separated the machinist from the mechanical engineer—they were, in fact, charter members of the ASME. Warner and Swasey met as apprentices and remained friends and business associates for the rest of their lives. When they set up their own firm in Cleveland, they worked together for twenty years without any written partnership agreement, formalizing their relationship only when the growth of their business necessitated incorporation. In their attitude toward what they were doing they scarcely exemplified the doctrine that business men are concerned solely with maximizing profits. Ambrose Swasey used to say that the lathes made the money but the corner of the shop devoted to astronomical instruments gave him the greatest enjoyment, and in the 1920's he refused to expand the plant because he did not want his technical and philanthropic interests curtailed by additional managerial responsibilities.

There are plenty of others who could be cited as examples; the last thing I wish to suggest is that the virtues I am describing are peculiar to Yankee toolmakers. The history of the Roebling family could be used to illustrate the same qualities, as could the life of John B. Jervis, who not only worked vigorously for the recognition of engineering as a profession in the United States but was one of the first to maintain that the education of the engineer also qualified him for what Jervis termed "the systematic management of business."

What I wish to emphasize is the recurrence in the history of American industry of men in positions of leadership who have taken with them the professional outlook acquired during a successful technical career. The total contribution of this group is much too elaborate for discussion

(Continued on page 26)

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† I am indebted for this information to Professor Robert S. Woodbury of the Department of Humanities at M.I.T., who is writing a comprehensive history of machine tools.

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January, 1960

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The Unique Properties of Flexure Pivots

FRED S. EASTMAN
Professor of Aeronautical Engineering

F. S. Eastman

Flexure pivots may consist of one or more flexible strips, wires, or specially shaped pieces of material rigidly attached to two parts in a way that permits rotation of one part relative to the other by elastic deformation of the flexible material. The rotation attainable without damaging the flexible material may be only one degree or it may be more than 30 degrees, depending upon the magnitude and frequency of the load applied, the properties of the material, and the type of construction. Inexpensive construction may be used where precise repetition of the hinge action is unimportant. In such cases, a flat piece of belting material may be superior to the usual pin-connected hinge because it absorbs vibration and requires no lubrication. But high-grade spring material and suitable care in construction make possible characteristics that cannot be equaled by the best ball-bearing, jeweled-bearing, or knife-edge pivots.

When a flexture pivot is rotated from its neutral position, the resulting stresses in the flexible material oppose the rotation by a restraining action like that of a spring. Unlike the friction in ordinary bearings, this restraint is precisely repeated in successive cycles of rotation. Moreover, if ideal elastic behavior could be attained, no energy would be consumed and the restraint would increase from zero at the neutral position exactly in proportion with the angle of rotation, as indicated in Fig. 1 by the straight line, A. In practice, there will be at least a trace of inelastic behavior, which becomes quite prominent when very flexible materials are used, as indicated in Fig. 1 by curve B. By using care in construction and in selecting the flexible material, actual pivot behavior can be made to approach the ideal so closely that the difference is hard to detect, even when precision tests are performed for this purpose. The substitution of such pivots for friction-type bearings can lead to important improvements in force-sensitive devices.

COMMON APPLICATIONS OF FLEXURE PIVOTS

Of the many different applications of flexible connections that are in use today, the provision of ball-and-socket action at the ends of linkage rods is perhaps the simplest. Often the use of a rod with short necked-down sections at each end, as shown in Fig. 2(a), is sufficient. If greater flexibility is needed about the axes perpendicular to the rod, it can be obtained by cutting away the rod at each end so as to leave two thin strips, one set at 90 degrees from the other, as shown in Fig. 2(b). In most other applications an important feature is a firm axis of rotation capable of withstanding loads applied in any direction. For this reason the more elaborate crossed-flexure arrangement shown in Fig. 2(c) has come into wide use. Similar arrangements of nonmetallic flexible connections introduce some damping that helps to avoid vibration and damage from shock loads.

The difficulty of manufacturing flexure pivots with precisely defined elastic properties tends to limit their use to applications in which restraint plays only a secondary part. Linkages that transmit forces under essentially static conditions fall into this category because the pivots do not rotate more than a fraction of a degree. Frequently, under such conditions, all that needs to be known is that the restraint is essentially proportional to the angle of rotation. Almost any method of construction that employs strips of good spring material will satisfy this requirement.

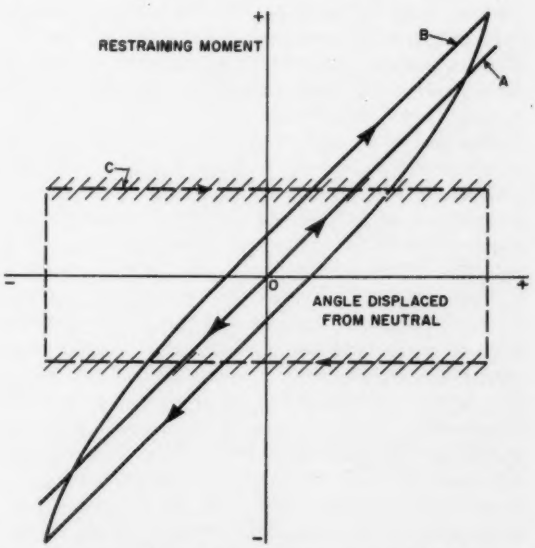

FIG. 1. ELASTIC AND FRICTIONAL RESTRAINT COMPARED
A, Ideal elastic behavior; B, Elastic behavior of very flexible materials; C, Bearing-friction restraint

General Design Considerations

The flexible strips should have different proportions, depending upon the conditions to be met. For example, an unusually large length-to-thickness ratio is advantageous when the pivot is to support almost no load, because the maximum angle of rotation can be increased by this design proportion. On the other hand, an unusually low length-to-thickness ratio is better when the pivot is to support a heavy load with almost no rotation. With no load the rotation is limited only by the bending stress, but with no rotation the load is limited by the column strength of the strips.

Most uses for flexure pivots fall between these limits, so that the maximum stress in the strips is the sum of the bending stress from rotation and the axial stress from the load. The maximum angle of rotation depends upon the load; it is reached when the maximum stress equals the stress limit. This limit depends upon the material and upon the use to be made of the pivot. A downward adjustment in stress limit may be needed in some applications to avoid the possibility of failure through continuously repeated cycles of rotation. An additional downward adjustment may be needed for applications requiring unusually high precision, because the actual elastic behavior approaches the ideal elastic behavior more closely under reduced stress levels.

The Stiffness of Crossed-Flexure Pivots

As a result of the restraining action of the flexible material, crossed-flexture pivots develop a restoring moment that, for small angles of rotation at least, is very precisely proportional to the angle of rotation. The magnitude of the restoring moment, M, is defined in terms of pivot stiffness, k; the angle of rotation, θ, by writing $M = k\theta$. The stiffness of a pivot is, like that of a spring, constant; but theoretical and experimental studies show that it decreases when the load subjects all the strips to tension and increases when the load is reversed and all the strips are in compression. The change in stiffness is not exactly proportional to the load, but it can be kept nearly so by designing the pivot so that it operates within a restricted range, as illustrated in Fig. 3. For applications in which constant stiffness needs to be maintained, crossed-flexure pivots should be loaded as in Fig. 4 because this arrangement puts two strips in compression while the other two are subjected to tension of the same magnitude. The result is that the increased stiffness owing to compression is approximately compensated for by the decreased stiffness owing to tension. With care in design, pivot stiffness will remain constant within very close limits. Actually, a slight reduction in stiffness occurs when a load is applied; but the reduction, which is negligible when the load is small, increases approximately as the second power of the load. This reduction is illustrated in Fig. 4. For this reason an oversize pivot designed to operate at a fraction of its normal working load should sometimes be substituted. But we must remember that pivot stiffness is increased by this substitution, and that the only reduction is the change in stiffness with load.

Minimum Stiffness with No Load Applied

According to theory, the no-load stiffness can be reduced indefinitely simply by using strips of greater width and correspondingly less thickness and length, so that the cross-sectional area and the length-to-thickness ratio remain unchanged. Carrying this procedure to an extreme, we obtain zero stiffness when the width becomes infinite and the thickness zero. In practice, construction difficulties increase rapidly as the width-to-thickness ratio is made greater than 10 to 1. To understand the reason for this increase, consider a sample pivot assembly having four strips, each with 20/1 length-to-thickness and 10/1 width-to thickness ratios. With the pivot in neutral position, each of the strips is to withstand a force of 25 lb without exceeding a stress limit of 25,000 psi. To meet this requirement, the strips must be 0.2 in. long, 0.1 in. wide, and 0.01 in. thick.

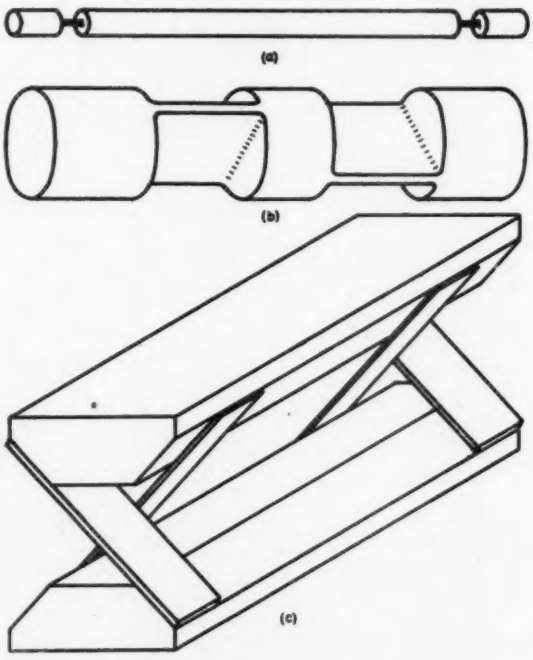

Fig. 2. Common Appl'cations of Flexure Pivots
(a) Ball-and-socket sections at rod ends; (b) Rod-end with two thin strips; (c) Crossed-flexure pivot

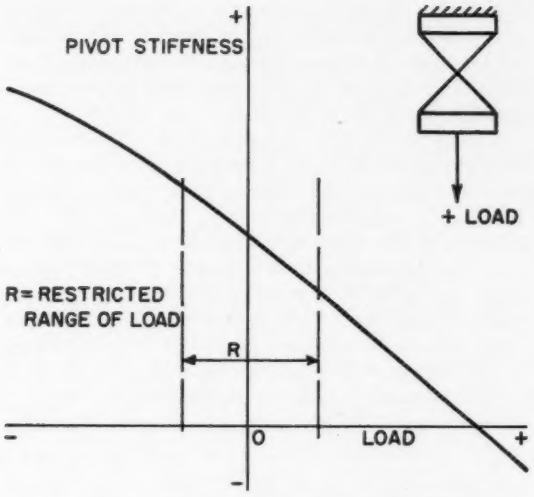

FIG. 3. EQUALLY STRESSED CROSS-FLEXURE PIVOTS
Stiffness is nearly proportional to load within a restricted range.

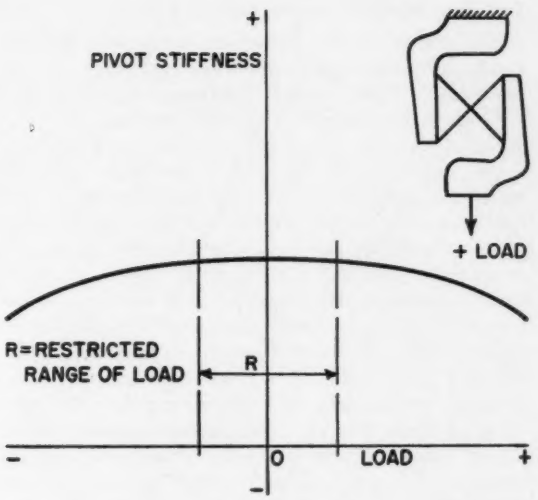

FIG. 4. PIVOTS LOADED FOR CONSTANT STIFFNESS
Stiffness is nearly constant when range is sufficiently small.

Now let us consider the effect of increasing the width-to-thickness ratio to 1000/1. To provide the same cross-sectional area and length-to-thickness ratio, the new dimensions must be 0.02 in. long, 1.0 in. wide, and 0.001 in. thick. According to theory, a crossed-flexure pivot with strips of this size will have only 1/10 the stiffness of the sample pivot, although it will support the same load. Actually the new dimensions are impracticable unless very special construction methods are developed, because the assembly must be more than four in. wide and because misalignment or curvature of only a fraction of a thousandth of an inch in the strips will have a pronounced influence on the elastic behavior of pieces so extremely thin. Ultimately the construction of pivots approaching this extreme may be possible, but only after a gradual expansion of the practicable limit as experience is gained with different methods of construction.

RESTORING MOMENT AND BEARING FRICTION

Elastic restraint is not numerically comparable with the friction of ordinary bearings, but a helpful concept of the relative magnitude of the restraining action is obtained by comparing the restoring moment caused by one-degree pivot rotation with the friction moment of a good ball bearing. The no-load restoring moment is representative because this value does not change essentially when loads are applied as in Fig. 4. As shown by analysis,[3] the no-load restoring moment is $M = EI\theta/L$. By expressing the moment of inertia in terms of thickness, t, and width, b, and using $\theta =$ 0.01745 radians to represent one degree of rotation, the restoring moment of a single strip may be written $M = (Ebt^3)/(687L)$. In terms of the stress limit, f, each strip will support the load $P = btf$ when the pivot is in its neutral position. If this relation is used to define the area, bt, the restoring moment at one degree of rotation becomes $M = (PEt^2)/(687fL)$. For the two pivots previously considered, $P = 25$, $L/t = 20$, $f = 25{,}000$, and $E = 29{,}000{,}000$ if the strips are made from steel. Therefore the restoring moment is $M = 2.11t$ for each strip; and the total restoring moment of the four strips of the same pivot, for which $t = 0.01$, is 0.0844 lb-in. The total load that can be supported by the four strips set at 90 degrees, as in Fig. 4, would be $4 \times 0.707 \times 25 =$ 70.7 lb.

The friction moment of a small ball bearing, capable of supporting the same load, is subject to considerable variation. Based on a friction coefficient of 0.001 and the assumption that the friction force is applied at a radius of 0.2 in., the friction moment is 0.01414 lb-in. This is less than 1/6 of the restoring moment of the sample pivot, but pivots can be constructed with much less stiffness if this is the main requirement. For this reason the restoring moment caused by one degree of pivot rotation certainly can be reduced to about the magnitude of the friction moment of a good ball bearing having the same load capacity. This concept should be used with caution when the load is changed, because very small ball bearings tend to have relatively greater friction moment, whereas large ones have less.

The Importance of Precision Types

The use of flexure pivots on levers and linkages employed under static conditions can increase the precision of force-sensitive systems to a much higher level than is attainable with ball bearings. In such applications the restoring moment remains very small, since it is proportional to the slight unavoidable pivot rotation. Usually this rotation can be kept less than 0.01 degree, so that the restoring moment remains less than one per cent of the friction moment of an equivalent ball bearing, according to the foregoing concept based on one-degree rotation. More important than this, the usual influence of friction on repeatability will be eliminated, because the elastic behavior of existing flexure pivots, when subjected to such a small angle of rotation, is practically frictionless. Even though some evidence of inelastic behavior may be observed in very sensitive devices, it probably will be imperceptible when improved flexure pivots offer a closer approach to ideal elastic behavior.

A much greater potential need exists for precision flexure pivots on sensitive measuring and control devices that require a considerable amount of pivot rotation. In these applications the restoring moment caused by pivot rotation becomes large enough to play an important part in the response of the device. Under such circumstances precision tests may have to be made on many complete assemblies before all the undesired influences can be eliminated. For this reason the cost of pivots of this type tends to become prohibitive when a small number are to be used. On the other hand, it may be practicable to develop one or more standard series that can be used to great advantage on high-precision devices of all kinds. Certainly the availability of flexure pivots with precisely known elastic properties could stimulate their use in many new areas, in just the same way as ball bearings have come to replace other kinds of bearings.

Methods of Precision Construction

Good crossed-flexure pivots can be constructed by clamping four thin strips of spring material between carefully machined blocks to obtain the arrangement shown in Fig. 2(c). Some unpredictable elastic behavior may be detected in such pivots, however, because thin strips cut from spring material are not precisely flat and because friction occurs between the highly stressed portions of the strips and the clamping blocks. Attempts to avoid these difficulties have led to the use of specially formed flexible elements for large pivots. Often a block of steel is machined so as to leave a thin strip with large ends shaped to fit firmly in end blocks designed to hold four such strips in precise alignment. This type of construction avoids friction by reducing the stress level at all points of contact; but, because the steel must have good machinability, the choice of material is limited. The work of machining and grinding to precisely the desired size is difficult: this process tends to distort the flexible strips, and it is impossible to achieve satisfactorily when the strips must be extremely small.

Probably the best elastic properties will be obtained by pressing the thin strips from a thicker strip of the desired material. In this way, accurately formed strips with enlarged ends can be made quickly from the best elastic material, and at a very low unit cost if a sufficient demand develops for them. Precision pivots designed for very low stiffness will demand strips having the largest practicable width-to-thickness ratio. Subassemblies, each consisting of a single pair of strips lying in one plane, appear to offer particular advantages. Finish honing can be done on these subassemblies to remove any remaining irregularities or misalignment.

Secondary Effects of Pivot Rotation

A crossed-flexure pivot constructed with adequate care offers the most nearly frictionless and the most rigidly fixed axis of rotation imaginable as long as its rotation from neutral position remains within a fraction of a degree. Its restoring moment is precisely proportional to the rotation and has a maximum magnitude that is near the vanishing point. Strictly speaking, secondary effects are present, but they are undetectable when the pivot is rotated only slightly from its neutral position. These effects remain inconsequential for most applications through four degrees of rotation, and for some purposes they are negligible even beyond eight degrees.

The flexible strips of a crossed-flexure pivot curve more and more as the pivot is rotated. The curvature is distorted when a load is applied, so that the distance between opposite ends of each flexible strip changes slightly with each change in load. The distortion introduces secondary effects that increase from zero when the pivot is turned from its neutral position, in which the strips are straight, and the load causes only axial shortening or lengthening of the strips. One result of these secondary effects appears as an increase in the displacement of the hinged part under the influence of load, so that axis rigidity tends to decrease as the pivot is rotated from its neutral position.

Even under no-load conditions the hinged part rotates about an axis that moves through an undetectable distance at first but through a greater distance as the pivot continues to turn. This effect is illustrated by the travel of the reference point on the hinged block of the equivalent linkage shown in Fig. 5. In addition to this, calculation[1] shows that the simple proportionality between restoring moment and pivot rotation changes perceptibly when the pivot

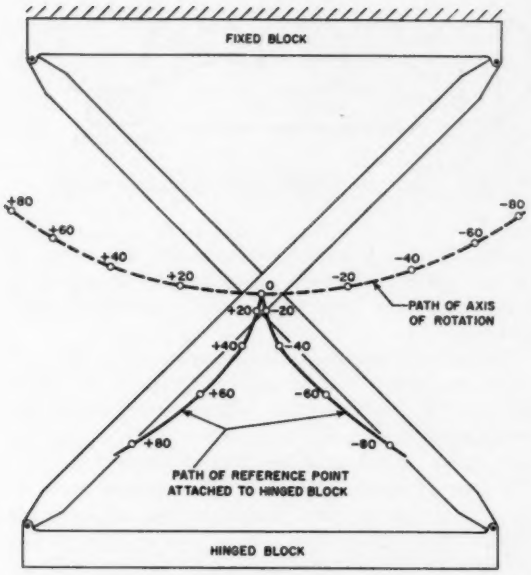

FIG. 5. MOTION RESEMBLING THAT OF FLEXURE HINGE
Numbers indicate degree of rotation from neutral; plus sign means clockwise.

is rotated through angles in excess of eight degrees.

The magnitude of the secondary influences is so slight when pivots are turned no more than eight degrees that they are likely to be overshadowed by unpredictable properties. These properties arise from the characteristics of the material and from imperfections in the pivot assembly. Fortunately these unpredictable properties tend to vanish as the angle of rotation is reduced, so that precision pivots for use at small angles of rotation are not difficult to obtain.

GAINS FROM IMPROVED ELASTIC BEHAVIOR

The change in stiffness of a crossed-flexure pivot when a load is applied, as in Fig. 3, provides a means of adjustment that is advantageous in many applications. For example, a beam hinged with this pivot arrangement can be loaded by applying weights until the tension of the strips is such that stiffness becomes precisely zero, or until it has a particular positive or negative value. A slight negative value may be needed to counteract excessive stiffness arising from other parts of the system on which the pivot is used. In other applications changing the stiffness in known steps is advantageous. This can be done by providing a suitable means for changing the weight. Devices subject to acceleration or changes in orientation with respect to gravity must avoid the use of weights, but a spring-loading device can be substituted; and the force that it exerts can be transmitted through an auxiliary flexure pivot to the hinged part. Variables

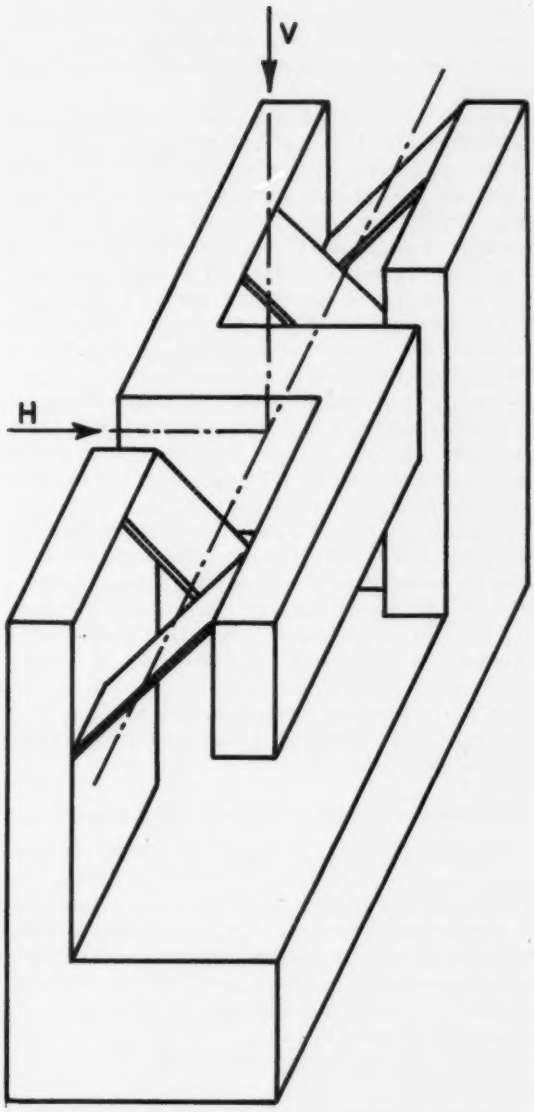

FIG. 6. SPECIAL CROSS-FLEXURE PIVOT
Stiffness remains essentially constant, even with different combinations of H and V.

such as pressure, temperature, and voltage can be made to control pivot stiffness in this way, the only requirement being to apply a corresponding load on the pivot.

As has been pointed out, there is no apparent change in stiffness when the pivot is loaded within certain limits, as in Fig. 4. The pivot assembly shown in Fig. 6 will show no apparent change, even if the load varies in direction as well as in magnitude,

since both the vertical component, V, and the horizontal component, H, will subject two of the strips to compression and the other two strips to an equal tension.

Special advantages will appear for many different assemblies, but the most far-reaching improvements in flexure pivots may be expected when pyramid types are perfected for general use. This type employs flexible connections inclined from the axis of rotation like the edges of a pyramid, as shown in Fig. 7, so that rotation of the pivot causes torsion as well as bending in the flexible elements. In Fig. 7 the pivots are three wires spaced 120 degrees apart around the axis of rotation; they are staggered or bridged to avoid contact at their midpoints. Axial tension is controlled to obtain the desired stiffness. An early experiment with this type of pivot has been described,[2] and also a tripod pivot arrangement.[3] Up to the present time the crossed-flexure arrangement has been preferred, because it is easier to construct. The pyramid type can have better characteristics for high-precision work, however, particularly when rotation must be in excess of four degrees, because its axis of rotation tends to remain precisely fixed and because the undesirable secondary effects can be avoided to a large extent by making use of torsional deformation of the elastic elements. Almost any desired elastic behavior is relatively easy to obtain from this type of pivot through special means for controlling the axial force, T.

The Need to Develop Pivots for General Use

The ultimate design in elastic-type pivots promises unique properties that can be used to advantage in a great many applications and to satisfy an urgent need in high-precision devices. These properties will not be obtained through scattered efforts, in which there is no opportunity to integrate all the experimental evidence. A suitable long-range development program may be feasible, however, if an improved type of pivots can be sold in substantial quantity for general use.

The use of flexure pivots will increase manyfold if they become available at moderate cost in convenient sizes and types of assembly, all in conformance with published elastic properties. There seems to be a need for so many different kinds of construction, however, that no one pivot is sure to be used in large quantity. The table on page 11 may help to clarify the problem. Symbols are entered in the second column to indicate the types of pivots that may satisfy the condition described on the corresponding line in the first column.

The following types are listed: pivots constructed of very flexible material; a single metal strip with good elastic properties; the usual crossed-flexure pivot with good elastic performance; the crossed-flexure pivot with some compensating or adjusting feature; and any improved variety, such as the pyramid type.

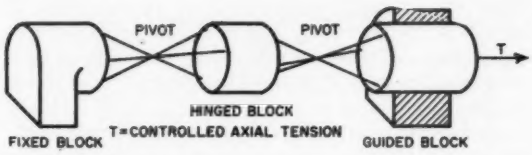

Fig. 7. An Arrangement of Pyramid Pivots

Conditions requiring pivot rotation up to four degrees can be satisfied by any of the pivots described in the table. But the table indicates that, under this limitation, the *s* pivot is satisfactory when it supports only ¼ its rated load at the neutral position and that the *x* pivot is satisfactory when it supports only ½ its load at this position. Under conditions requiring precise repeatability, the *s*, *x*, or *p* type of pivots can be used under constant load conditions, but only the *x* and *p* types are suitable under varying load conditions. The *x* type can be used as in Fig. 4 if the load is unidirectional, but the x^+ type will be needed if the load is multidirectional. Pyramid pivots with certain elaborations may prove satisfactory under almost any conditions; and, since the *p* type includes these and other improved pivots that may appear later, such pivots are considered satisfactory for all the conditions listed. A combination of *f* and *x* types may provide good axis rigidity at unusually large pivot rotation because very long metal strips can be embedded in a flexible material that will tend to stabilize the strips.

Apparently metal-strip construction can be used to advantage under almost every combination of conditions. Any preference for *f* pivots is likely to arise from their simplicity rather than from any special advantage offered by this type. Therefore thin strips of the best elastic material may be used ultimately in almost all applications of flexure pivots, if these materials become available at low cost and in forms that are easy to assemble. This fact gives added assurance that the development of flexure pivots for general use is feasible, because large quantities of these superior flexible elements certainly can be produced economically in each of several different sizes and proportions. They will prove useful for on-the-job assemblies as well as for all the many different kinds of complete pivots to be made available for general use. All pivots constructed in this way will be better and less costly than corresponding ones made by existing methods, and more complete use can be made of their elastic properties, since these will be known in advance.

TABLE I

CONDITIONS OF USE RELATED TO TYPE OF CONSTRUCTION

Conditions To Be Satisfied			Pivot Construction That Can Satisfy the Conditions*				
Item No.	Degrees Rotated from Neutral Position	Load Supported (Fraction of Rated Load at Neutral Position)					
1	1	(1/5) †	*f*		*x*	x^+	*p*
2	4 or more	(1/5) †	*f*				*p*
3	1	1/2 †	*f*	*s*	*x*	x^+	*p*
4	4	1/2 †	*f*		*x*	x^+	*p*
5	8 or more	1/2 †	*f*				*p*
6	1	1/4 †	*f*	*s*	*x*	x^+	*p*
7	4	1/4 †	*f*	*s*	*x*	x^+	*p*
8	8	1/4 †	*f*		*x*	x^+	*p*
9	more than 8	1/4 †	*f*				*p*
10	To withstand heavy shock load		*f*				*p*
11	To be precisely repeatable (under constant load) ‡			*s*	*x*	x^+	*p*
12	To be precisely repeatable (under varying unidirectional load) ‡				*x*	x^+	*p*
13	To be precisely repeatable (under varying multidirectional load) ‡					x^+	*p*
14	Control of stiffness necessary (Manually; by temperature, pressure, etc; or in steps)					x^+	*p*
15	Need for axis rigidity (Negligible displacement, even when load is multidirectional)				*x*	x^+	*p*
16	Axis position precisely fixed (Position unaffected by rotation)						*p*

* Pivots that may prove suitable for supporting these loads have been judged from "The Design of Flexure Pivots."[3]

† *f* Pivots using very flexible material
s Single flexible strip of good elastic material
x The ordinary crossed flexure of good material and construction
x^+ The same as *x*, but with additional adjusting or compensating features
p Possible improved types, including the pyramid type

‡ Restoring moment must be precisely the same every time the pivot is returned to a given position.

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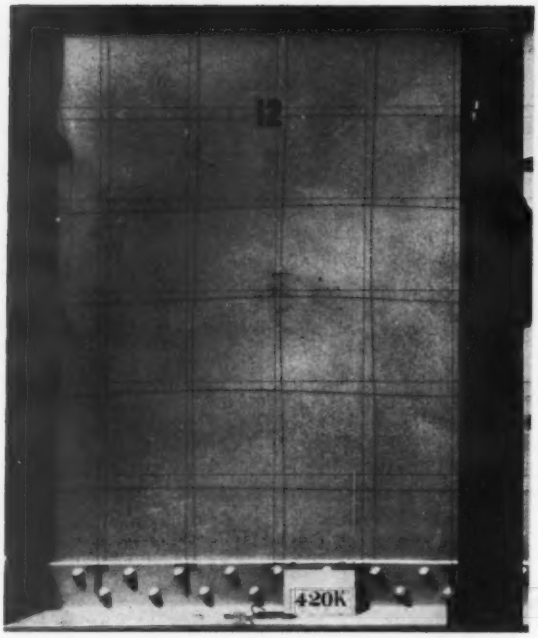

FIG. 1. SHADOW PICTURE SHOWING DEFLECTION

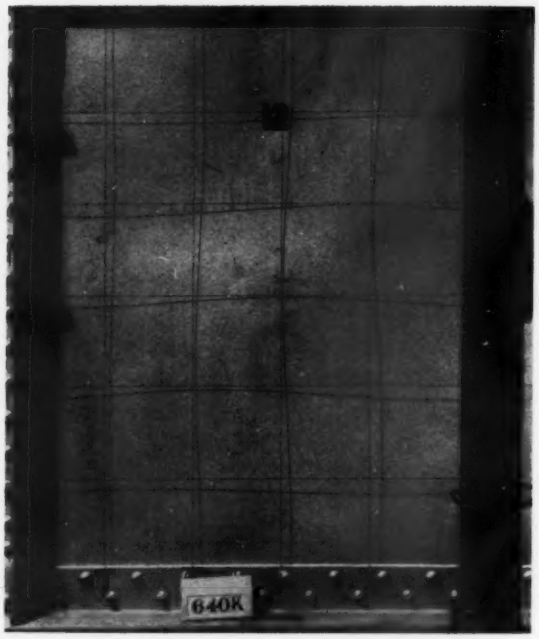

FIG. 2 PICTURE SHOWING MARKED DEFLECTION

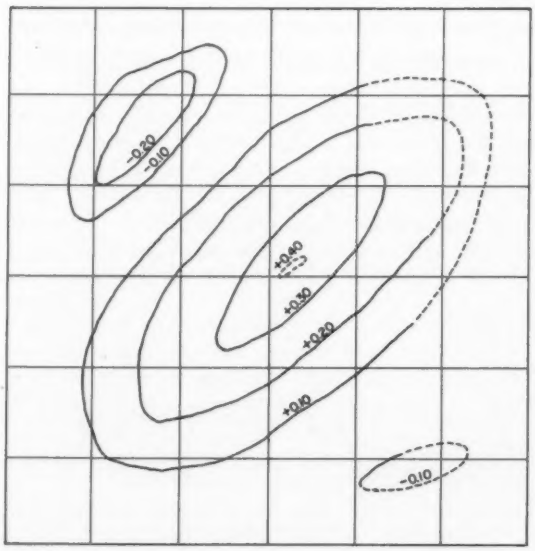

FIG. 3. CONTOUR OF DEFLECTION (AT 420 KIPS) SHOWN IN FIG. 1

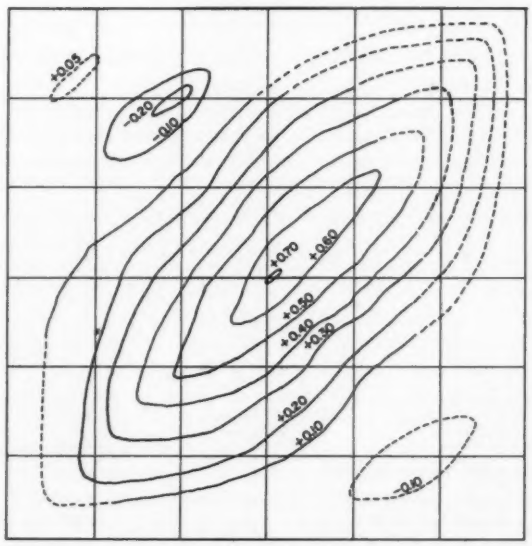

FIG. 4. CONTOUR OF DEFLECTION (AT 640 KIPS) SHOWN IN FIG. 2

A Photographic Method for Determining the Deflected Shapes of Buckled Plates

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In the theoretical analysis of the problem of buckled plates, the deflection is expressed in the form of a double trigonometric series. Physically the buckling appears in the plate surface as a wave formation that can be observed in actual tests. A generally adopted method of determining the deflected shape of a plate in experiments is to make direct measurements with dial gages. After the deflections at a large number of points on the plate are carefully measured, a contour plot can be made to show the deformed shape of the plate.

Although this method permits great accuracy in the measurement of deflections, it is not an entirely satisfactory procedure. It involves many inconveniences when the plate to be measured is large because it requires either a great number of dial gages or an elaborate movable support so that the measurements can be made at a sufficient number of points. This procedure extends the testing period by the time necessary for numerous measurements; and sometimes the testing machine may be very difficult to hold long enough at a definite load without variation. Furthermore, the result of the observations is a list of figures that, unless plotted as contours, do not provide a picture of the deflected plate. If a mistake occurs in the data, almost no means of checking is available.

However, a solution to these difficulties can be easily found by using the photographic method described in the paragraphs that follow. In explaining this method, let us take the plate-girder tests conducted in the Structural Research Laboratory of the University of Washington as an example.† The figures used in this article illustrate the methods used and the plates tested.

D. D. Vasarhelyi

In the experimental study of the behavior of the web plate of the plate girder, the purpose was to obtain the deflected shape of the web plates at various stages of loading. This was done by the use of photographs taken on the web plate, which bore a system of shadow lines caused by a grid pattern suspended in front of it. Specimens of the shadow picture are shown in Figs. 1 and 2 on the opposite page.

By analyzing the shadow projections at a certain load and comparing them with the shadow picture of the initially undeflected web plate, the deflections of many points on the web could be calculated. After these calculations were made, contours showing the deflected shape of the web were plotted. Figures 3 and 4 are such contours, plotted from the photographs in Figs. 1 and 2.

Construction of the Grid

Figure 5 shows the arrangement of grid lines in a panel. In order to produce clear and distinct pictures, the web plate was whitewashed and black strings were used to form the grid pattern. In the vertical direction, the strings ran from the top flange angle to the bottom one, forming a set of vertical lines stretching across the plate at equal spacings. Since the flange angles are ¾ in. thick, the strings were strung at a distance of ¾ in. in front of the web plate. In the same manner strings were stretched horizontally from stiffener to stiffener, these strings being also ¾ in. from the surface of the web. Thus the horizontal and vertical strings formed a grid about 8 in. square in a plane parallel to and ¾ in. from the web plate.

The Shadow Pictures

A strong light was placed over a corner of the panel and held at such a distance in front of the girder that the rays of light were cast on the plate at a suitable inclination to the web. The camera was focused on the center of the panel and placed at a definite distance in front of the girder. Once the

* Mr. Yuan, who received his M.S. Degree in Civil Engineering in 1959, is now working as draftsman-designer at the Star Iron and Steel Co. in Tacoma.

† "An Experimental Investigation of the Behavior of a Riveted Plate Girder with a Thin Web," unpublished report to ASCE-AASHO Task Committee on Plate Girders, Aug., 1959.

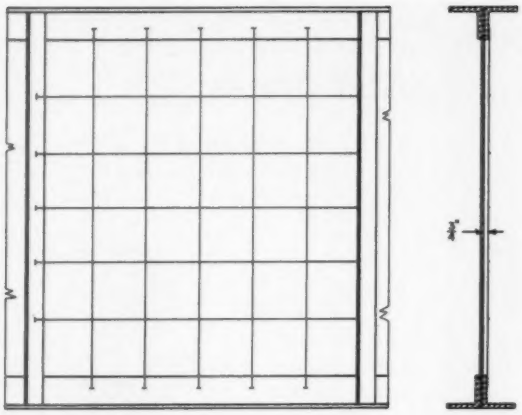

FIG. 5. ARRANGEMENT OF GRID LINES IN A PANEL

positions of the camera and the light were fixed, they were always placed at the same positions whenever a picture was taken.

To calculate the deflection of the web at a certain loading, the shadow pictures of the undeflected plate had to be used as a basis of comparison. This picture was taken at an applied load of 10 kips. With this load the deflections are negligible when compared to those expected at several hundred kips. A grid picture taken at panel 12 of the plate girder is shown in Fig. 6. After the reference pictures were taken, the test could go on and a series of pictures could be taken at the loadings desired. An advantage of this method is that it provides ready at hand a picture of the deformed surface of the plates. Just by looking at the curved shadow lines alone, one can tell how the plate buckles. In this manner any mistake in the calculation of deflection is easily detected.

In addition to photographs, moving pictures were also taken of the web during the course of the test. By projecting the film at a suitable speed, one can readily observe the process of deflection and the formation of buckles in the web through the progressive change in the shadow pattern of the grid.

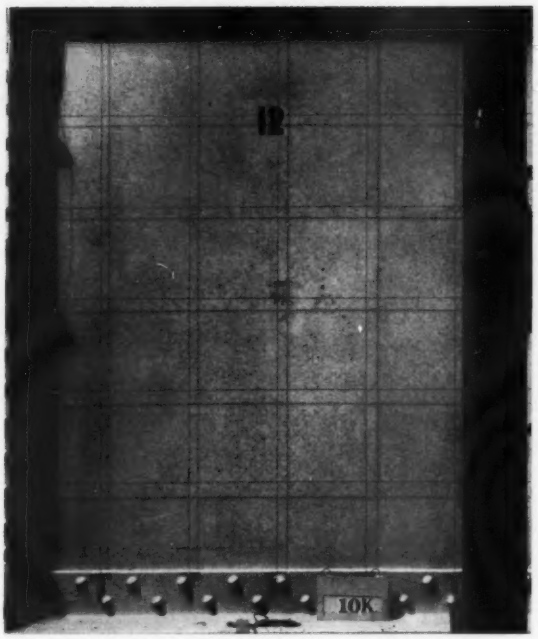

FIG. 6. PANEL 12 SHOWING NEGLIGIBLE DEFLECTION

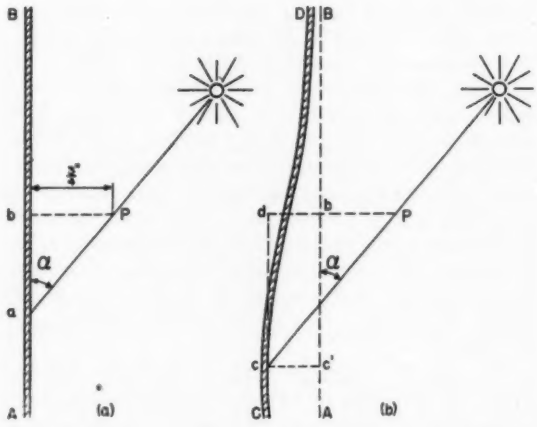

FIG. 7. THE METHOD OF CALCULATING WEB DEFLECTION

The Method of Calculating Deflections

To illustrate the method of calculating the deflection of the web, let us first consider the shadow of a point on the grid as an example.

Let P in Fig. 7(a) be a point on the grid ¾ in. away from the web plate; and let a ray of light inclined at a definite angle, α, to the plate cast the shadow of P on the plate at a. In this figure the plate AB is shown in its undeflected position. If a photograph is taken in a direction perpendicular to the plate, it will show the projection a and the point P (which coincides with the point b on the plate); therefore the distance ab can be scaled off from the photograph.

Now if the inclination of the light and the position of the point P remain unchanged and the plate is deflected from its original plane, AB, to a new posi-

tion, CD, the shadow of the point P on the deflected plate will be changed to C as shown in Fig. 7(b). If another picture is taken with the camera at the same position as before, it will show the position c and the point d (coinciding with P), and the distance cd can be measured from the picture with the same scale. In Fig. 7, (a) and (b), the triangles Pab and Pcd are similar triangles. Accordingly, ab : cd = Pb : Pd. Since the ratio of ab to cd can be obtained by comparing the two photographs and the distance Pb is known to be ¾ in., the distance Pd can be calculated by simple proportion. Then the deflection of the point c from the original plane can be easily obtained from the relation c'c = bd = Pd - Pb. On account of the method used, the deflection we obtained is actually at the point of c' instead of at the point b.

The manner in which the web deflections were calculated from the grid pictures is shown in Fig. 8, (a) and (b). Here we take the points of intersection of the horizontal and vertical strings as working points. Let Fig. 8(a) represent the grid shadow of the undeflected plate and Fig. 8(b) be the shadow picture of the deflected web plate at an applied load of, say, 500 kips. Let us first calculate the deflection of one of the intersection points, P. From Fig. 8(a), the distance ab can be scaled off a_0, and with the same scale the distance cd can be measured from Fig. 8(b) as a_1. Knowing that the clearance between the string and the original position of the plate was h = ¾ in., we obtain

$$a_0 : a_1 = h : h_1$$

and

$$h_1 = h\frac{a_1}{a_0} = \frac{a_1}{a_0}(¾ \text{ in.}).$$

If w represents the deflection of the point c from the original undeflected position by w, then

$$w = h_1 - h = h_1 - ¾ \text{ in.}$$

Proceeding in the same manner, we can estimate the deflections at all of the points of intersections of the shadow lines in Fig. 8(b) at 500 kips. By interpolation, a system of contour lines representing the web deflection at this particular load can be plotted.

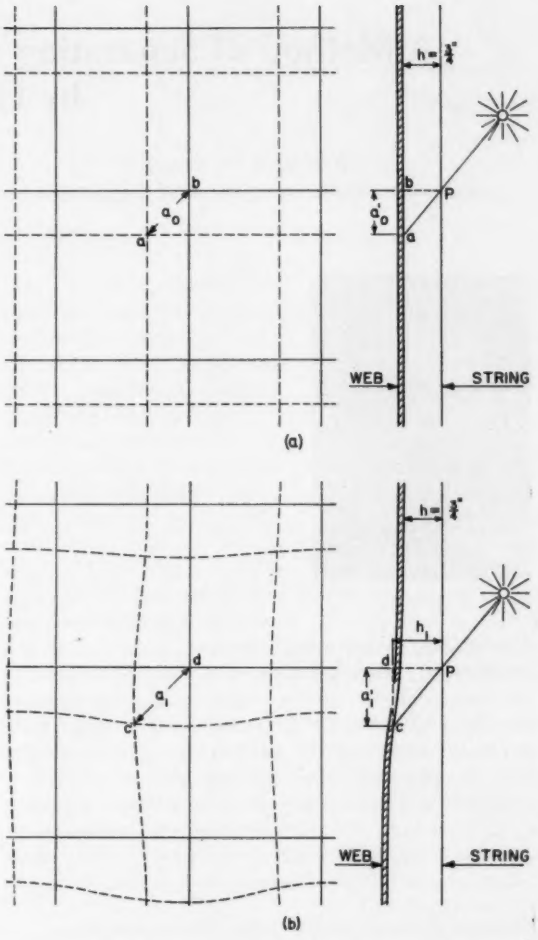

FIG. 8. PROJECTING A POINT ON (a) UNDEFLECTED AND (b) DEFLECTED WEB PLATE

Conclusions

As is apparent, this method of calculating the deflected shape of the web has certain inherent inaccuracies. These are about as large as those generally associated with graphical methods and, of course, they can be minimized by scaling the dimensions from the photographs very carefully.

This method proved especially helpful in forming a qualitative picture of the buckled web. After the observer became familiar with the method, he could visualize the deflected shape of the web by merely studying the shadow pattern. By applying and removing the load on the girder quickly, he could visualize the formation of the buckles in the web panel, which, of course, could not be noticed without the aid of the shadow pattern. The dial gages used to measure the deflection of the web served as a means to check several points on the contour plot constructed from the shadow pattern. It is believed that the method described for determining the contours, used in conjunction with the dial-gage readings, provided a fairly complete picture of the deflected shape of the web panels.

A Method of Separating and Concentrating Cinnabar by Flotation

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Domestic mercury production has long suffered from foreign competition, and the price has fluctuated greatly, eventually rising from $75 to $240 per flask. At the present time it has stabilized at approximately $200. While the price has climbed, consumption has almost doubled in the past twenty years. This growth can be attributed to expansion in the chlorine and caustic-soda plants using mercury, as well as to the increase in pharmaceutical and dental-preparation markets and to nuclear-engineering applications. Government subsidies in the form of a guaranteed purchase price and the backing of exploration for new deposits have aided domestic production.

Mercury is primarily from a sulfide, cinnabar (H_gS), though livingstonite and the native metal are also mined. The major deposits in the United States are found in California, Nevada, and Alaska.

Current Methods in Cinnabar Concentration

The general means of recoving mercury is by roasting the ore after a minimum of crushing. The ore is charged directly to the furnace, where, at a temperature of 500 to 600° C, it decomposes readily to yield mercury in a vapor form ($H_gS + 0_2 \rightarrow H_g + S0_2$).

This decomposition of the sulfide is possible after a minimum of crushing, the extent of crushing being determined by the porosity of the associated gangue materials. The reason for direct furnacing without concentration is that cinnabar is generally so friable that it becomes too fine for gravity concentration. Within recent years several mercury mills have introduced into their operations flotation circuits that successfully concentrate the mercury before it is furnaced. Among these operations are the Bretz Mill of the Arentz-Comstock Mining venture in southeastern Oregon; the Battle Creek Mill of the Triangle Mining Company in Western Nevada; and the United Mercury Mill south of Lovelock, Nevada. The various types of ore treated by these plants are similar in that they are soft and claylike. Mercury recoveries above 90 per cent in a 30-50 per cent H_g concentrate are reported by all three operations.

J. D. Siddle

Although these mills do not face the problem of ore contamination, others do. In some mills the association of the mineral realgar (AsS) with cinnabar renders an ore difficult to treat. During the furnacing, the arsenic contaminates the final product, causing losses and costly refining procedures. In order to render this type of ore more amenable to economic development, an effective process for separating the realgar and cinnabar would be desirable. A literature survey showed that work had been done on flotation as a means of solving this problem; and an examination of the results of this work indicated that further effort at achieving a sharper separation of the realgar and cinnabar would be warranted. To find such a method, consistent with higher mercury recovery, was the object of this investigation.

Basic Procedures in This Study

Previous studies of cinnabar reveal that the mineral is easily floated by using a xanthate collector along with a metal salt, such as copper sulfate or lead chloride, and that, in general, the pH of the pulp is not critical within a reasonable range. For the present study, the most important source of information was the record of work carried out by the Northwest Electrodevelopment Experiment Station of the Bureau of Mines. This work provided the starting point for the investigation discussed here.

Previous testing made use of a variety of frothers, promoters, activators, and modifiers. The best results were obtained from a xanthate promoter, a copper-chloride activator, and a long-chain alcohol as a frother. The scheme giving the most satisfactory recovery starts with a rough arsenic float, which is made by adding only the xanthate promoter. After removal of all the floatable arsenic minerals, addi-

tional promoter is added, along with the copper chloride, thus activating the cinnabar and allowing it to be floated. The next step is to clean the arsenic float by adding frother; then a refloat is carried out. The overall recovery with this procedure was 83.2 per cent in a 6.00 per cent concentrate.

Since the results of these tests were very promising, they offered a starting point for a new investigation with the same kind of ore. It was believed that the use of basic flotation theory and a careful adjustment of variables might improve the results. Information obtained from the literature survey offered further possibilities of improved results.

Upon receipt of approximately 100 lb of a 4-in. run of mine ore, the first operation was to reduce it to -1 in. in the laboratory jaw crusher. The next step was to split the sample into two equal parts on the Jones' riffle. One fraction was tagged and stored for later use as required. The other fraction was crushed to -¼ in. and again split into two equal fractions on the riffle, one fraction being tagged and stored. The remaining fraction was crushed to -10 mesh and divided into 500-g samples.

Because the earlier work with the ore gave a very clear and complete insight into its mineralogical composition, a minimum amount of time went into this phase of the investigation. The minerals present were identified under the binocular microscope. Cinnabar and realgar were identified with ease because of their brilliant color; metacinnabar, quartz, and pyrite were also identified. In order to eliminate unnecessary assays, a procedure was developed wherein, after every series of tests, each fraction was examined under the microscope. Only after an examination indicated that the flotation procedure offered real possibilities was an assay conducted.

In the previous work on the ore it was discovered that, in order to liberate the mercuric sulfide, grinding to a 90 per cent -200 mesh would be necessary. A screen test was performed on the sample in order to study the degree of liberation in various fractions. From this study the grinding requirements recommended from the previous work were confirmed. Three screen analyses were carried out on different grinds so as to determine the correct grinding time. Table I is a screen analysis of the 26-minute grind.

Approximately thirty tests were carried out, of which ten were concerned solely with standardizing techniques and duplicating previous results. The remaining tests were carried out by using different approaches and reagents.

The cell operations were as follows:

1. After dilution to 20 per cent solids, the acidity of the pulp was adjusted to give a pH reading of 9.0. The reagent used was sodium hydroxide.

TABLE I

SCREEN ANALYSIS AFTER A GRIND

SIZE	WEIGHT (Grams)	WEIGHT (Per Cent)	CUMULATIVE PER CENT
65 mesh	.....	.....	.....
100 mesh	4.1	0.8	0.8
150 mesh	8.7	1.7	2.5
200 mesh	33.3	6.7	9.2
−200 mesh	451.6	90.8	100.0
	497.7	100.0	

Time	26 minutes
Proportion of Solids	60 per cent
Ball Load	6000 g
Speed	62 rpm
Mill Description	8 x 8 in. steel ball mill

2. Two and one-half ml of Z-200 in a 1 per cent water solution were added.
3. One ml of a 1 per cent water solution of F-80 was added, and this was followed by a two-minute conditioning.
4. A rough arsenic float was carried out. The float was continued until the froth appeared free of realgar, usually about 4 to 6 minutes. No attempt was made to maintain the pH of the pulp at its original alkalinity.
5. The pH of the pulp was readjusted to 8.0 by addition of sodium hydroxide.
6. Two and one-half ml of a 10 per cent cupric chloride water solution were added; two minutes of conditioning were used.
7. A mercury float was carried out until the froth showed no traces of cinnabar, usually 7 to 8 minutes being required.
8. The arsenic cleaner float was carried out by diluting the float product from the rougher float to approximately 20 per cent solids. The pH was adjusted to 9.0 with sodium hydroxide. The cleaner float was continued until no realgar appeared in the froth, generally about 4 minutes.

The flotation products were dried, weighed, and assayed.

The results obtained by following this procedure indicated that excessive mercury minerals were floating with the realgar. The results also indicated that a better separation of the cinnabar from the tailings would enhance results. With these facts in mind, trials were made of various procedures using the same reagents as in the previous test. The best results got

and the methods used are described in the following paragraphs.

Results of a Modified Procedure

By altering the sequence in which reagent additions were made, the results were improved. This improvement was possible only after frother was added to the rough arsenic float. The procedure was further altered in that no additional promoter was required for the mercury float, nor was further frother required after the single addition.

After the above adjustments have been made to the procedure, the sample responds very favorably. The realgar floats readily, even without frother and promoter. The froth formed is not thick, nor is it stable enough to remove until the reagents are added. Upon addition of the Z-200 and F-80, an excellent float was produced. The bubbles were heavily loaded and quite stable. In fact, some small difficulty was met in breaking them down after flotation. The exact end point of the rough arsenic float was rather hard to judge. If the float was carried on too long, excessive amounts of cinnabar began to appear. Examination of panned samples revealed an optimum point at which minimum amounts of realgar remained and a minimum amount of cinnabar was removed. The pH during flotation, if kept reasonably close to nine, was not found to be critical.

The addition of cupric chloride activated the cinnabar, producing a very good froth. It was very persistent; hence the flotation time was comparatively long. There was no clear end point to the mercury float. Instead, a large amount of gangue was floated, removing most of the cinnabar.

The arsenic cleaner float has all the characteristics of the rougher float; but great care was necessary to prevent removing an undesirable amount of cinnabar along with the realgar.

By using the modified procedure described above, a recovery of 85.73 per cent was possible in a concentrate assaying 15.95 per cent mercury. The concentration ratio was 1:11.4, and the ratio of As to H_g reduced from 1.62:1 to 0.207:1. The remainder of the mercury appeared chiefly in the As concentrate and the As tailings. The mercury values in the tailings were almost negligible. A metallurgical balance from this test is presented in Table II.

Examination of the flotation fractions under the microscope and study of the metallurgical balance indicated that the most obvious place for improvement was the cinnabar-realgar separation in the arsenic cleaner float. The trouble seemed to come partially from the entrainment and removal of cinnabar slimes with the realgar. The indecisiveness of the cutoff point for the cleaner arsenic float also appeared to cause complication.

TABLE II

Flotation Concentration from Modified Procedure

Product	Weight (Per Cent)	Assay (Per Cent)		Content		Distribution Per Cent	
		Hg	As	Hg	As	Hg	As
Hg Conc.	7.29	15.95	3.30	1.16	0.240	85.6	8.8
As Conc.	3.63	2.04	54.4	0.074	1.97	5.4	72.0
As Cl Tailings	0.84	12.20	21.8	0.102	0.183	7.5	6.7
Tailings	88.24	0.023	0.390	0.02	0.344	1.5	12.5
	100.00			1.356	2.737	100.0	100.0

Flotation Time

Conditioning	6 minutes
Arsenic Rougher	5 minutes
Arsenic Cleaner	8 minutes
Mercury Float	4 minutes

Reagent Consumption

Dow Z-200	0.1 lb/ton
$CuCl_2$	1.0 lb/ton
Frother F-80	0.04 lb/ton

pH Conditions

Natural pH after dilution	6.6
Arsenic Floats	9.0
Mercury Floats	8.0

The Procedure Using Dispersing Agent

The preceding test suggested that a cleaner realgar-cinnabar separation would achieve more satisfactory results. For two reasons, sodium silicate was one of the more obvious separation reagents to use. First, previous investigations showed that this silicate has a depressing effect on cinnabar; hence the cinnabar would be less likely to float. Second, because sliming appeared to cause a large part of the trouble, a dispersing agent would tend to keep the fine slimes dispersed in the pulp.

The preliminary treatment of the sample was exactly the same as in the previous test, that is, a 26-minute grind at 60 per cent solids, and dilution in the cell to 20 per cent solids.

The cell operations were as follows:

1. The pH of the pulp was adjusted to 9.0 by using sodium hydroxide.
2. Two and one-half ml of a 1.0 per cent solution of Z-200 were added; two minutes of conditioning followed.

3. A rough arsenic float was carried out. This was continued until the froth appeared free of realgar and panning revealed little realgar on the bubbles. The time for this rough float was 4 minutes.
4. The pH of the pulp was adjusted to 8.4 with sodium hydroxide.
5. Two and one-half ml of chloride solution were added. One and one-fourth ml of frother F-80 solution were added. The pulp was conditioned two minutes.
6. A mercury float was carried out until the froth showed no cinnabar. The float time was 6 minutes.
7. The fraction from the rough arsenic float was placed back in the cell and diluted to approximately 20 per cent solids. One and one fourth ml of 10 per cent frother F-80 were added. One-fourth g of sodium silicate was added in a water solution. The pulp was conditioned for two minutes. The pH was 10.2 after addition of the sodium silicate.
8. A cleaner arsenic float was carried out until no realgar appeared in the froth. The flotation time was 4 minutes.

The flotation products were dried, weighed, and assayed.

Results from Use of a Dispersing Agent

Since examination under the binocular microscope revealed that the tailings from the cleaner arsenic float were equal in content to the mercury concentrate, these fractions were combined and assayed together; thus direct comparison with the preceding test was not possible.

After this test was made several times, it was found that to get the most benefit from the sodium silicate exactly 1 lb per ton must be added.

During the test, the addition of either more or less than the required amount of sodium silicate seemed to destroy the selectivity between the realgar and cinnabar. A more surprising discovery was that the addition of frother F-80 to the rough arsenic float could be omitted. This obvious inconsistency has not been explained. It was also noted that, to promote a good froth in both the mercury float and the arsenic cleaner, frother F-80 had to be added. The addition required for the mercury float follows from the fact that no frother was added in the rough arsenic float. It was thought that the addition to the arsenic cleaner was made necessary by the presence of the sodium silicate.

After these alterations had been made to the procedure, no trouble was encountered in the test.

Examination of the metallurgical balance in Table III shows that the concentration of mercury in the mercury concentrate was improved quite radically, the yield being a concentration ratio of 1:88. The

TABLE III

FLOTATION CONCENTRATION, SODIUM SILICATE ADDED

PRODUCT	WEIGHT (Per Cent)	ASSAY (Per Cent)		CONTENT		DISTRIBUTION	
		Hg	As	Hg	As	Hg	As
Hg Conc.	4.34	26.40	4.95	1.146	0.214	86.75	7.3
As Conc.	4.12	3.24	58.1	0.133	2.390	10.07	82.0
Tailings	91.54	0.046	0.34	0.042	0.312	3.18	10.7
	100.00			1.321	2.916	100.00	100.0

Flotation Time

Conditioning	6 minutes
Arsenic Rougher	4 minutes
Arsenic Cleaner	4 minutes
Mercury Float	6 minutes

Reagent Consumption

Dow Z-200	0.1 lb/ton
$CuCl_2$	1.0 lb/ton
Frother F-80	0.1 lb/ton
Sodium Silicate	1.0 lb/ton

pH Conditions after Dilution

Arsenic Rougher	9.0
Arsenic Cleaner	10.2
Mercury Float	8.4

recovery was 86.7 per cent, but this figure includes both the mercury recovered in the mercury concentrate and that remaining from the arsenic cleaner. The arsenic-to-mercury ratio has been improved from 1.63:1 to 0.19:1. The primary loss of mercury appears in the arsenic concentrate, where the distribution jumped from 5.4 to 10.1 per cent.

Tests using a mercuric salt all gave negative results, and so did a test in which sulfur dioxide was added. A series of tests using sodium cyanide showed no deviation from the results of the original test; so they were also considered to be negative.

Discussion of Results

The conclusion drawn is that differential flotation can be used to concentrate cinnabar from an ore containing arsenic minerals. By using a xanthate promoter, frother F-80, and a metal salt such as cupric chloride, the amount of arsenic in the sample was greatly reduced, enough to permit furnacing without undue complications. The most successful procedure established was a rough arsenic float followed by a mercury float. The arsenic-float product was later refloated to give an arsenic concentrate and a middling product. The major difficulty encountered was

obtaining a clean separation between the cinnabar and realgar during the arsenic cleaner float. By testing various modifying agents, an effort was made to improve this separation. Sodium silicate added to the arsenic cleaner float gave the best results, producing a good concentrate at a reasonable recovery.

All floats were made in a slightly alkaline pulp. The modifying agent, sodium hydroxide, was used to achieve alkalinity.

The greatest drawback to concentration and separation of the cinnabar by flotation was the very fine grind required to liberate the cinnabar. Since the grind was so fine, a great amount of sliming was encountered. Since most dispersing agents act as a depressant on the cinnabar present, the cinnabar cannot be depressed by common reagents tested during the rough float.

The major basis for improvement in flotation lies in separating the cinnabar and metacinnabar from the arsenic-bearing minerals. This separation is made possible by the fact that surface activation of the cinnabar and metacinnabar is necessary before extensive reaction with the xanthate promoter takes place. The separation is complicated by the extensive sliming from the fine grind. Since most common dispersing agents are also a depressant for cinnabar, the only place for a dispersing agent to be used is in the arsenic cleaner float, where the object is to float the arsenic minerals but retain the mercury minerals in the tailings.

It should be noted that the ore sample tested was unusually high in mercury content, 1.4 per cent as compared to 0.73 per cent in the sample tested by the Experiment Station. The arsenic-to-mercury ratio was likewise unusually low, the ratio being 1.6:1 as compared to 6.6:1. The sample used in the present investigation assayed 2.27 per cent arsenic. The main gangue mineral was quartz; also present were small amounts of pyrite, stibnite, and carbonaceous materials. The mercury was present in the form of cinnabar and metacinnabar; the arsenic, in realgar and a small amount of arsenopyrite. The mercury-bearing minerals were finely disseminated throughout the ore; grinding to 90 per cent -200 mesh was necessary for liberation.

The flotation experiment using only promoter F-200, frother F-80, and cupric chloride as an activator was successful in providing a furnacing concentrate at a reasonable recovery. The middling product is rather high in arsenic content to be treated directly in a furnace, but the per cent of recovery could be increased by recircuiting this tailing from the arsenic cleaner float back to the original rough arsenic float.

The test work revealed that the pH of the pulp is not critical as long as it has low alkalinity. The main problem in using this flotation procedure is to determine the correct length of time to continue the various floats. Since the cutoff points are not definite, there is always the likelihood of removing excessive cinnabar in the arsenic floats and in floating excessive amounts of gangue with the cinnabar in the mercury float.

The experiment in which sodium silicate was added produced a very good product as far as concentration was concerned. The recovery, while not quite so good as for the preceding test in which no sodium silicate was added, was within the limits that permit economic treatment.

The pH at which the floats were made was quite different from that of the preceding floats. This is true especially in the arsenic cleaner float, where the pH went up to 10. It should be noted that, among all the tests in which the addition of sodium silicate was varied, 1 lb per ton gave the optimum results.

The tailings from the arsenic cleaner float were high enough in mercury content that they could be combined with the mercury concentrate. The examination under the microscope revealed that the arsenic cleaner tailings were actually of higher cinnabar content than the fraction from the mercury float.

This investigation resulted in a flotation procedure that improved the separation of realgar from cinnabar and that permitted a high degree of concentration in the cinnabar product.

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IBM 610 USED COOPERATIVELY

The IBM 610 Automatic Decimal Point Computer, a small digital computer being leased by engineering departments at the University of Washington, has proved to be very adaptable. Since it was installed in February, 1959, this desk-side computer has been used to solve problems in almost every branch of engineering. For the first nine months the computer was supported by the Structural Research Laboratory, but now it is sponsored jointly by departments in the College of Engineering. It is now located in the Mechanical Engineering building; Professor Peter L. Balise is in charge of it.

Since it is a general-purpose machine, the 610 has almost unlimited usefulness. Although it cannot compete with a large computer in speed and capacity, it is a great time saver because it is much easier to program than the bigger machines.

The easy programming permits an inexperienced operator to solve quite complex problems. The computer consists of three physical units interconnected by flexible cables: (1) a cabinet containing the magnetic-drum storage unit, two paper-tape units, the control panel, and all the necessary electronic equipment; (2) the keyboard, which allows the operator to communicate with the computer; and (3) a high-speed electric typewriter with which the computer can type the results.

The IBM 610 was designed to solve problems within the computation area between that of the desk calculator and that of the large electronic computer. It can also be used in checking a program for a large electronic computer. It has a type of floating decimal point called "auto point" that automatically positions the decimal point for all arithmetic operations. When the auto point is used, the sign of the number and 30 digits—15 on each side of the decimal—are carried in the machine; this arrangement makes possible the solution of almost all engineering problems without the necessity of scaling or the introduction of a scale factor. The magnetic drum has a capacity of 80 numbers, each with 30 digits plus their algebraic sign. If additional storage is needed, numbers can be stored on one of the paper-tape units.

In solving a typical problem the operator first assigns a drum-storage location to all numbers used in the calculation. Then, working from the keyboard, he solves the problem in much the same manner as he would on a desk calculator. At the same time the machine punches a paper tape containing all the instructions. If the problem is to be run again with different values or if the solution is being obtained through iterative process, the punched program tape is put into the machine, and the instructions from the tape are automatically executed.

The control panel provides the machine with the ability to make decisions. A problem may be such that, depending on the size of an intermediate result, the remaining computing may take one of several paths. In this way a general program can in many cases adapt itself to special problems. The panel is also used for subroutines that are programs for general categories, such as sines, cosines, and logs being used within a specific program. This feature enables the operator to just refer to a specific routine on the panel instead of having to put into his program a separate procedure for finding, say, a sine, because the program on the panel can find the sine automatically. Many such routines are on a panel so that in most cases the operator need not worry about them.

Besides operating in the "auto point" mode, the 610 computer may operate in fixed point. When the machine is in fixed point, it will run a little faster, but the scaling of all numbers is taken into account in the program. This mode is generally used in checking a program for a larger computer because the larger ones generally work in fixed point. The IBM 610 also can do all arithmetic operations in octal form—that is, with eight different digits instead of ten as in the decimal system. Numbers in the octal system can be easily converted into binary numbers, a system with only two different digits that is used on many of the large electronic computers.

Routine problems are solved quickly. Programs for the most general engineering problems, such as the solution of simultaneous equations, are already made and are on file. Because a program is already made on a punched tape, the operator needs only to supply his data from the keyboard. The machine will proceed automatically, getting its instructions from the paper tape.

Research is another field that illustrates the adaptability of the 610. In many research studies there are several completely different approaches to a problem. These are explored quickly on the 610 because it is easily programmed; then only one program has to be made for the faster and more complicated computer.

The IBM 610 has also proved to be a useful classroom aid. It is simple enough for a student to use without extensive instruction, and it serves as a stepping stone for a student who is interested in larger computers, the understanding of the big ones being much easier after apprentice work with the IBM 610. With this assistance more students have the opportunity to become acquainted with the fast-growing field of computers.

CHARLES W. BOWER
Research Assistant

Experiment in Space-Flight Living Economy

An experimental investigation of a means to enable sustenance for men during space flight is now in its second stage of operation in the College of Engineering at the University of Washington. Dr. Richard H. Bogan, Associate Professor of Civil Engineering, is making this study under a contract with the Aero-Space Division of the Boeing Airplane Company. Dr. David D. Chapman and Mr. Lowell Ericsson of the Biosciences Branch of the Aero-Space Division have participated in the work.

The chief aim of the investigation is to determine the feasibility of using the activated sludge process, which is widely employed in treating sewage and industrial waste products, as a means of transforming human wastes into potential sources of plant food and drinking water. If it proved practicable, this process could assure a closed biological system within the space vehicle. The environment within this restricted travel compartment should be in a cyclic balance, equivalent to that of the world, but on a miniature scale. The plant components of the system should provide a gas exchange of oxygen for carbon dioxide and the reclamation of wastes in a form pure enough for consumption.

Other studies have been made of the problem of balanced sustenance and waste disposal during space flight, but most of the work has been theoretical. The closed system particularly fits extended flights, for it apparently offers the best prospect of weight reduction.

Professor Bogan completed the first stage of his experiment last September. By studying an activated sludge culture developed in an experimental pilot plant, he obtained information on biochemical oxidation, maximum temperature range, process-loading limits, and the output of carbon dioxide and nitrogen. The desk-scale pilot plant employed during preliminary studies is pictured in Fig. 1. Aerobic cultures were established on the wastes at a number of temperature ranges, and cell tissue was harvested and tested. The cultures subsisted entirely upon diluted excreta, a mixture of feces and urine from subjects on a low-fiber diet.

This experiment proved that the rapid stabilization of human wastes in a closed system is possible through use of the activated-sludge procedure. This first setup also provided design criteria for a full-scale laboratory pilot plant, which is now in operation.

The second pilot plant, shown in Fig. 2, was recently placed in operation in More Hall. It was designed to handle the waste products of as many as four people. Performance at a number of loading levels is being studied, and the process is to be loaded to the point of failure. An attempt also is being made

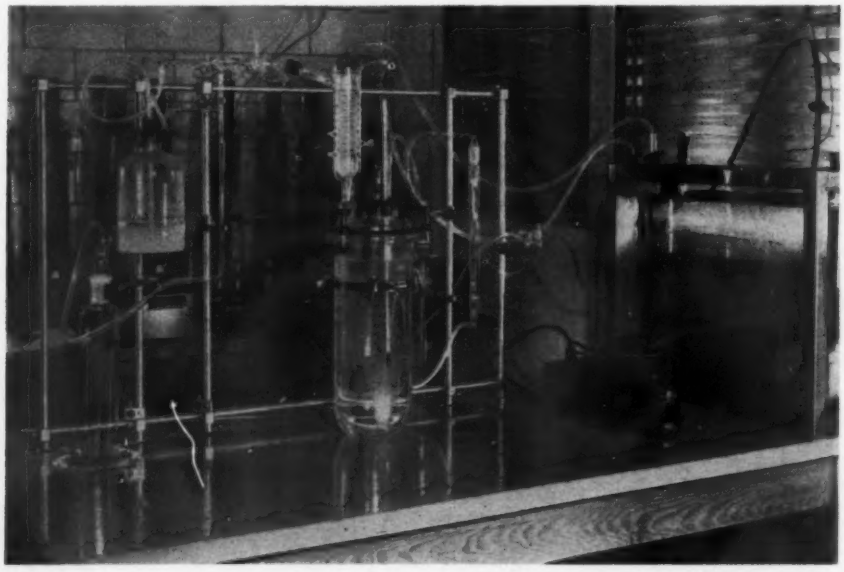


FIG. 1. THE DESK-SCALE PILOT PLANT

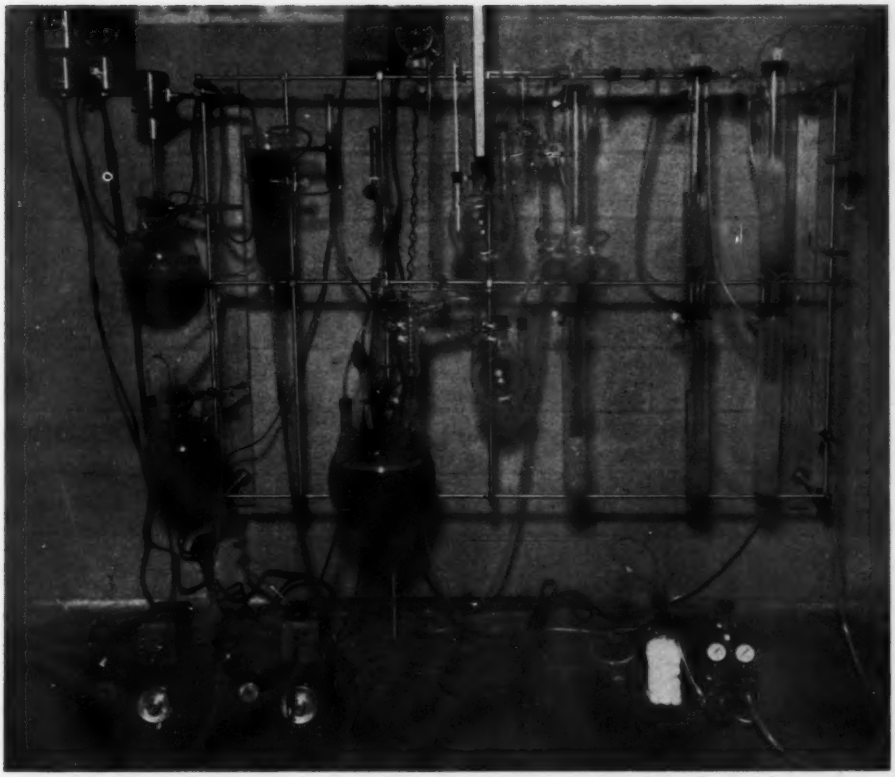


FIG. 2. THE FULL-SCALE LABORATORY PILOT PLANT

to establish an aerobic, thermophilic-activated sludge culture and to determine thermophilic reaction rates. Also under investigation are the factors that regulate NH_3 and CO_2 outputs—such factors as evaporation rate, aeration rate, and process loading. Answers to these questions are basic requirements for product control.

On January 16, the results of this work were presented at a regional meeting of the American Astronautical Society in New York City.

NEW RESEARCH CONTRACTS

The University has received final approval of a research contract, which provides a grant of $76,800, with the Rome Air Development Center of the U.S. Air Force. The contract calls for work on a project entitled "Information Theory Application to Mechanical Translation." Two members of the Department of Electrical Engineering, Dr. David L. Johnson and Professor H. Myron Swarm, will supervise the research. The grant is for the period from October 1, 1959, to March 1, 1960.

This project is part of the world-wide effort to develop mechanical language translators. Articles in *The Trend in Engineering* for July, 1958, and July, 1959, discuss the problem and describe some of the background research on it at the University.

Another grant, which also has final approval, is from the National Science Foundation. It provides $32,800 for research on "Diffusion in and Optical Absorption By III-V Compounds." Dr. Ling Y. Wei of the Department of Electrical Engineering will supervise the work. The grant is for the two-year period from July 1, 1959, to June 30, 1961.

New Building and Reactor to Match Graduate Nuclear Program

A boost in facilities for graduate education in nuclear engineering was assured on December 19, when the University of Washington Board of Regents awarded a contract for the construction of a Nuclear Reactor Building on the campus. The firm of Jentoft and Forbes of Seattle, the low bidder, was given the contract on a total bid of $262,655. Including fees, contingencies, and taxes, the total cost of the building has been budgeted at $308,082. Work on the two-story concrete and glass structure will start immediately on the hillside between More Hall and the Mechanical Engineering Building. Architects are The Architect Artist Group of Seattle. A special feature of the design is an observation deck for viewing the reactor from outside the building.

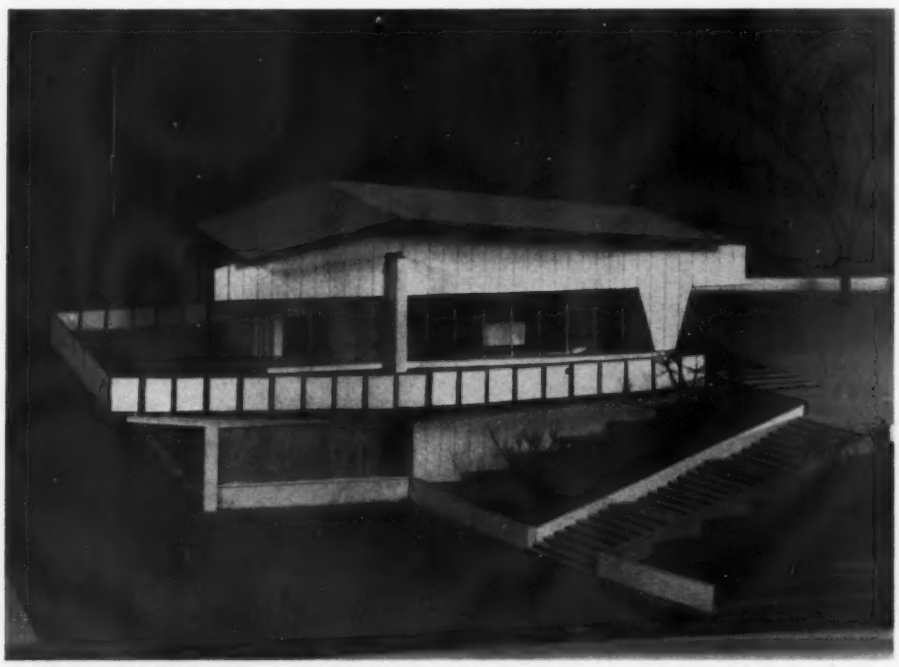
The reactor is now being built by AMF Atomics of Greenwich, Connecticut; and some parts for it have been received on the campus. A $150,000 grant from AEC will help finance the purchase and installation of the reactor. It is expected to go into operation next August.

The new reactor will be used primarily for graduate training in nuclear technology. It will serve as a basic facility in the University's comprehensive nuclear engineering program, which leads to a M.S. degree in engineering. The program is a cooperative undertaking of the departments of chemical, civil, electrical, and metallurgical engineering. It is administered by a faculty committee under the chairmanship of Dr. A. L. Babb, Asociate Professor of Chemical Engineering, who will be the reactor supervisor. Priority in the use of the reactor will be given to the graduate students. Dr. Babb says that a training reactor is generally more suitable than larger research reactors for educational purposes. Too often, research reactors are tied up by long-term experiments, leaving little time for their use by students in laboratory course work.

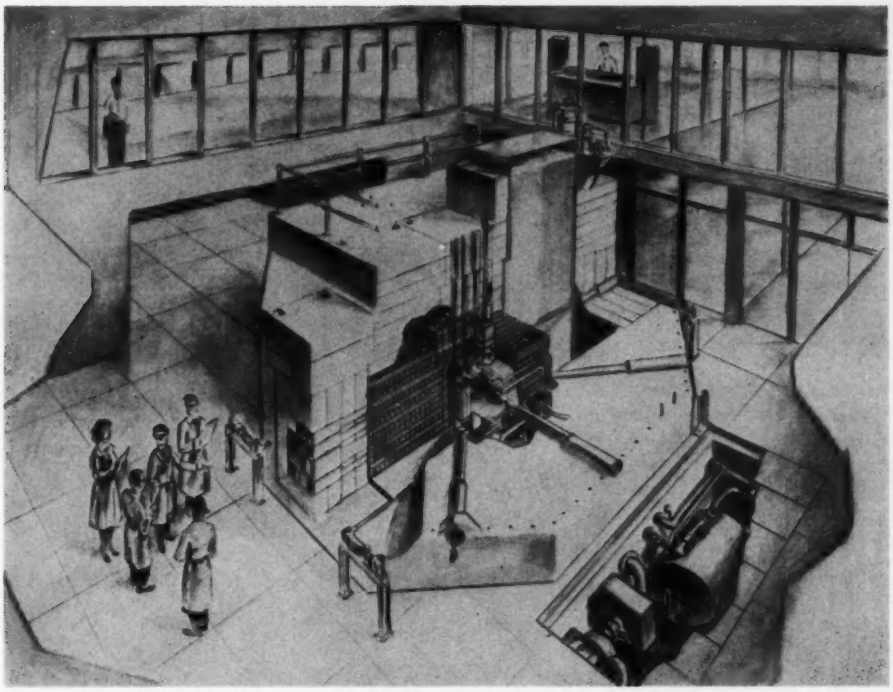
Design Features of UWTR

The University of Washington Training Reactor was designed after the Argonaut, which was constructed by Argonne National Laboratory, Lemont, Illinois. An Argonaut was operated as part of the U.S. exhibit at the 1958 Atoms-For-Peace Conference in Geneva, Switzerland. The UWTR is similar to one just completed at the University of Florida and another to be built at UCLA. These reactors were designed by Dr. Walter Zinn, formerly the director of Argonne National Laboratory, and associates, who worked with AMF Atomics.

The UWTR is capable of producing a self-sustain-



ARCHITECT'S MODEL OF THE NEW REACTOR BUILDING



MANUFACTURER'S SKETCH OF THE UNIVERSITY REACTOR

ing chain reaction. Its uranium-aluminum alloy fuel plates are enriched in the fissionable isotope uranium-235. Plates of this type were originally developed for the Materials Testing Reactor at Arco, Idaho.

In the reactor the fuel plates are assembled in six vertical aluminum fuel boxes arranged in two rows of three each. Between the two rows of fuel boxes is a 12-in. slab of graphite, and the entire core assembly is surrounded by another slab of the same thickness that acts as a neutron reflector. The reactor will be cooled by circulating water upward through the fuel boxes at a rate of 10 gal per minute; it will be controlled by four semaphore-type blades that will operate in enclosures between the fuel boxes. In an emergency, a dump valve will drain the fuel boxes quickly; and the control blades, which will fall by gravity into the reactor, will shut the reactor down. The core and graphite reflector are embedded in a 14-ft cube of concrete equipped with a removable concrete plug to provide access to the fuel elements.

General Procedure of Operation

In practice, slightly more fuel is added to the reactor than is required just to maintain the neutron chain reaction. The reaction is controlled by cadmium blades that are inserted into the fuel-plate assembly to absorb excess neutrons. By moving the cadmium blades slightly outward, excess neutrons are made available for experimental purposes. These neutrons are available in six beam tubes that penetrate the reactor shield to within a few inches of the fuel boxes in the core.

A large tank of water will be provided at one end of the reactor for shielding studies and for the irradiation of large samples. For small samples, a pneumatic tube system similar to those used in department stores will convey a sample in a plastic "rabbit" to the core, where it can be irradiated for the production of short-lived isotopes or other purposes and, after a given length of time, removed.

Every safety means known to nuclear technology has been provided in the design of the reactor, and these will be maintained during the construction and assembly of the UWTR. The reactor is limited to a thermal power of 10 kw. The water used in it is circulated continuously between the reactor and a storage tank; and all radioactive impurities will be removed. These waste products will be sealed in special containers and shipped to Hanford for burial in a special graveyard for radioactive wastes. A University radiological safety officer will supervise personnel monitoring practices.

Engineering Research Dividends

ALMOND, J. C., "Design of Packed Bed Catalytic Reactors Using a Digital Computer," M.S. in Chemical Engineering, 1959.

A method for the design of axial-flow cylindrical catalytic reactors has been programmed for an IBM 650 digital computer. The use of the computer offers much improvement over previous graphical methods, both in saving time and in being less limited in complexity. The computer method permits these considerations: (1) the diffusion of both heat and mass radially and axially; (2) the radial variation of lateral diffusion coefficients; (3) the radial variation of mass velocity; (4) the variation of heat capacity with temperature; and (5) a variable wall temperature.

By using this program, a study was made of the reaction system investigated by R. E. Hall and J. M. Smith as reported in 1949. This study reveals the relative effect of the various design factors involved. In particular the value and variation with radius of the radial Peclet group is of prime importance in this system. The merit of various determinations of the Peclet group as reported in the literature is discussed with reference to their application to reactor design. A need is apparent for data on the simultaneous turbulent diffussion of mass and heat.

LUX, P. A., "Application of Statistics and Information Theory in Finding Optimum Antenna Patterns," M.S. in Electrical Engineering, 1959.

This paper is concerned with finding the optimum directivity pattern of an antenna. Because of irregularities in the atmosphere or ionosphere, or because of meteor bursts, a signal does not arrive at the receiver from one direction only. Therefore maximum directivity with its attendant narrow beam width is not always the best criterion. An omnidirectional antenna with its low directivity is not likely to be the best either. However, a directivity pattern between these two extremes results in optimum performance. The optimum directivity pattern is determined by the type of signal to be received and the receiver being used. This optimum pattern is found as a function of the probability distribution of the incoming signal power.

TUTHILL, W. E., "Nucleate Pool Building in Accelerating Systems," M.S. in Engineering, 1959.

This experimentation was conducted to determine the effect, if any, that acceleration forces have on nucleate pool boiling.

The study was conducted by using a Pyrex pipe containing distilled water and a heating element which could be rotated together at various angular velocities. Acceleration forces were radially directed toward the heating element by the mechanism of centrifugal force. The values of accelerations thus produced were between 20 and 40 times the local acceleration of gravity. Heat-transfer rates per unit surface area of the heater element were 100,000 to 200,000 Btu/hr ft^2. The effects of acceleration were determined from measurement of the temperature differential between the heating element and the distilled water.

Results of the tests conclusively showed that acceleration forces suppress the heat-transfer coefficient. The results may have considerable importance in view of the use of nucleate boiling as a heat-transfer medium in rapidly accelerating systems such as missiles and rockets.

NOT JUST TO SELL

(Continued from page 1)

here, but I would place at the top of the list the implanting of this pride in the product which demands that it be usable as well as saleable.

Perhaps a word of caution is due here. In Henry M. Leland's statement, "Cadillacs are made to run, not just to sell," the word "just" has to be given its proper weight. Mr. Leland meant to sell his cars, and indeed did so quite successfully. I remember a left-wing organization some years ago—maybe it still exists—pushing the slogan, "Production for use and not for profit," as if the two were mutually exclusive. If we may judge by the record, this notion is completely refuted by the ability of American industry to produce for both use and profit and in so doing to make goods and services available to the ordinary individual on a scale which no one else has as yet been able to match. A substantial part of the credit for this achievement has to go to the Lelands and Swaseys, who insisted on precision in technique and reliability in performance.

We cannot, however, pat ourselves on the back over this record and let it go at that. It is peculiarly the responsibility of the engineering colleges and the engineering societies to see that the tradition which these men personify is carried on. As a first step, manifestly there should be continuing emphasis on the codes of ethics of the professional organizations, but this in my judgment is not enough, particularly for the large proportion of engineers who move from strictly professional activities into managerial functions. At the risk of appearing to grind a personal axe, I wish to suggest that engineers ought to be much more familiar than they are with the history and traditions of their own profession. They should appreciate that they share in the heritage of Benjamin Wright and Laommi Baldwin and Herman Haupt and the host of others whose standard of integrity and pride in performance made them require, like Henry Leland, that what they did was "made to run, not just to sell."

Notes and Comments

PROGRESS IN GREEN LAKE WATER-QUALITY AND ECOLOGICAL STUDY

Robert O. Sylvester, Professor of Sanitary Engineering, and George C. Anderson, Research Assistant Professor of Oceanography, are completing a year-long study of Green Lake and its environment. The purpose of this work is to determine the existing and past condition of the Lake, factors contributing to its present state of eutrophication, and what practicable measures may be taken by the City of Seattle to restore the Lake to its full recreational potential. They have been assisted on the study by four graduate and three undergraduate students.

The principal concern in this study has been the heavy algae blooms and their source of fertilization, together with a determination of possible existing or potential sources of pollution. At the request of the City, an investigation was made of possible schemes for improving the water quality in time for the 1959 bathing season. An interim report was submitted to the City in April of 1959 recommending the installation of a chlorination facility at West Beach. The recommendation was successfully followed last summer by using a recirculation pump to disperse chlorinated water through three diffuser lines and utilizing wind-driven currents to move the chlorinated water in the bathing area. Next month a final report on the study is to be submitted to the Seattle Park Board.

FALL-QUARTER MEETINGS

Four faculty-graduate colloquia in structures and mechanics were held in the College of Engineering during the fall quarter. B. J. Hartz, Associate Professor of Civil Engineering, was the coordinator of the following meetings:

1. October 27, a meeting held jointly with the Hydraulics and Fluid Mechanics Group; Speaker, Dr. Hunter Rouse, Director of the Iowa Institute of Hydraulic Research.
2. November 10, A. L. Miller, Professor of Mechanics and Structures; subject, "Earthquakes."
3. November 24, Frank Neumann, Seismologist, Department of Geology; a discussion of "Lateral Forces due to Earthquakes."
4. December 8, D. H. Polonis, Associate Professor of Metallurgical Engineering; subject, "Some Recent Developments in Metallurgy of Interest to Engineers."

On November 17 a technical session was sponsored by the Seattle Joint ASCE-ASME Committee on Applied Mechanics. Papers were given by E. H. Dill, Associate Professor of Aeronautical Engineering, whose paper was entitled "Large Deflection Equations for Thin Elastic Shells," and C. N. De Silva, Engineer, Boeing Airplane Company, whose subject was "On the Particular Solutions of the Small Deflection Equations for Thin Elastic Shells."

ENGINEERS IN THE NEWS

R. G. Joppa, Associate Professor of Aeronautical Engineering, and **E. P. Richey,** Associate Professor of Civil Engineering, have been awarded National Science Faculty fellowships for the next academic year. Professor Joppa will give fifteen months of time to study and research in flight dynamics; Professor Richey will study hydraulic engineering at the Technological University, Delft, the Nederlands.

G. S. Schaller, Professor of Mechanical Engineering, has published a second edition of *Engineering Manufacturing Methods* (McGraw-Hill); the first edition was issued in 1953.

Twenty-seven bound volumes make up the scientific reports of **John F. Pratt,** pioneer Northwest engineer and oceanographer, which the University Library acquired recently.

R. G. Hennes, Professor of Civil Engineering, has been appointed to membership on a newly authorized ASCE committee on Highway Transportation Policy. Professor Hennes has also been appointed Chairman of the Division of Economic Studies, a section of the Department of Economics, Finance and Administration of the national Highway Research Board.

J. L. McCarthy, Professor of Chemical Engineering, and **D. A. Ratkowsky,** Instructor in Chemical Engineering, presented a paper at the meeting of AIChE in San Francisco on December 8. The paper was entitled "Gas Absorption Accompanied by a Pseudo First Order Ionization Reaction."

N. N. Rao, Research Assistant, and **H. M. Swarm,** Professor of Electrical Engineering, were co-authors of a paper Rao delivered at the fall meeting of the American Committee of URSI in San Diego on October 20. Their paper was entitled "On the Semidiurnal Lunar Variations of Ionospheric Layers."

D. H. Polonis, Associate Professor of Metallurgical Engineering, has been awarded a grant of $15,000 by the National Science Foundation for research in phase transformations in copper-silicon alloys.

New Study of Highway Economics Reviewed

Studies of the Central Business District and Urban Freeway Development: Edgar M. Horwood and Ronald R. Boyce with the assistance of Lillian L. Randolph and Donald F. Rieg. Published by the University of Washington Press in cooperation with the Bureau of Public Roads of the U.S. Department of Commerce and the Washington State Highway Commission. Seattle, 1959. xiii and 184 pp. $5.00.

This volume is the latest in a series of highway economic studies produced at the University of Washington. The research reported upon here (as well as that in the companion volume *Studies of Highway Development and Geographic Change*) was carried out at the request of the Bureau of Public Roads of the U.S. Department of Commerce as part of the work called for by Congress in the Highway Revenue Act of 1956.

This study examines the structure of the central business districts of a number of American cities, and seeks to relate observed structural changes in the CBD to the development of urban freeway networks. The first section of the work is introductory in nature, providing a good review of current knowledge of the CBD as well as presenting the details of a "core-frame" concept that forms the basis for much of the subsequent analysis. Section two examines the two primary land uses in the CBD—retail sales and office space—in the light of changes that have taken place since the end of World War II. The analysis in this section rests mainly upon the comparison of the slopes and intercepts of simple regression lines. The results would have been greatly strengthened had the authors seen fit to report the results of their significance tests rather than leaving the reader to assume that all differences mentioned are significant. Also the analysis of trends in retail sales rests heavily upon the conversion of data to standard 1948 dollars. The authors leave unanswered the question of how this was done (the reviewer assumes that deflation was accomplished by means of the Consumer Price Index). The third section presents three sample studies of decentralization and suburbanization. Insurance offices were found to have decentralized from 30 to 40 per cent during the postwar period, while electric utility offices and banking deposits tended to remain central. Reasons for differences in trends between various land uses are examined in detail.

The results of the empirical analysis reported upon in the first three sections form the basis for a discussion of transportation implications in section four. The authors set the stage through a discussion of the nature of urban freeway and expressway systems and then attempt to evaluate the impact of these systems upon the central city. It is pointed out, quite correctly, that our knowledge concerning land-use structure and its relationship to transportation can only be classed as elementary, and as a result any discussion must be presented in very broad terms involving some degree of subjective analysis. For a variety of reasons, the authors feel that the impact of urban freeway systems will be mainly felt in the outlying CBD frame rather than in the core areas. They also point out that transportation-induced changes to date are probably minimal because of the existence of only a few urban freeway routes and particularly because of the absence of freeway networks.

An appendix by Professor Leonard D. Goldberg provides an interesting discussion of the tax implications of highway impact research.

This study will be of interest to urban planners, highway engineers, and other persons interested in the changing structure of our large cities.

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PACIFIC-AREA ASTM MEETING

The American Society for Testing Materials held its Third Pacific Area National Meeting in San Francisco on October 11-16. Three University staff members and a recent graduate were authors or co-authors of papers presented at the meeting. The program, which included 28 technical sessions, covered topics ranging from *Adhesives, Air-Pollution Control,* and *Ceramics in Nuclear Energy* through *Spectroscopy, Thermal Ablation,* and *Wood in Building Construction.* The University was represented as follows: Professor Martin I. Ekse (Civil Engineering) and Henry C. Morris (M.S. in Civil Engineering, 1959), "A Test for Production of Plastic Fines in the Process of Degradation of Mineral Aggregates"; Henry C. Morris, "The Effect of Particle Shape and Texture on the Strength of Non-Cohesive Aggregates"; and Professor Richard H. Meese and Richard W. Long (Instructor in General Engineering), "Triaxial Compression Tests on Soils Using Variable Lateral Pressure."

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2. Iron and Steel Manufacture in Washington, Oregon, California, and Utah. Joseph Daniels. 69 pp. 1929.
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3. The Theory of Fractional Parts Developed for Structural Beam-Column Members Preceded by an Elementary Discussion of Simple Beam and Column Design. Sybren Ruurd Tymstra. 32 pp. 1943.
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